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Agriculture, Ecosystems and Environment 82 (2000) 247–259

Agriculture Ecosystems & Environment

www.elsevier.com/locate/agee

Scaling up from field to region for wind erosion prediction using a field-scale wind erosion model and GIS

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Abstract

Factors that affect wind erosion such as surface vegetative and other cover, soil properties and surface roughness usually change spatially and temporally at the field-scale to produce important field-scale variations in wind erosion. Accurate estimation of wind erosion when scaling up from fields to regions, while maintaining meaningful field-scale process details, remains a challenge. The objectives of this study were to evaluate the feasibility of using a field-scale wind erosion model with a geographic information system (GIS) to scale up to regional levels and to quantify the differences in wind erosion estimates produced by different scales of soil mapping used as a data layer in the model. A GIS was used in combination with the revised wind erosion equation (RWEQ), a field-scale wind erosion model, to estimate wind erosion for two 50 km^2 areas. Landsat Thematic Mapper satellite imagery from 1993 with 30 m resolution was used as a base map. The GIS database layers included land use, soils, and other features such as roads. The major land use was agricultural fields. Data on 1993 crop management for selected fields of each crop type were collected from local government agency offices and used to 'train' the computer to classify land areas by crop and type of irrigation (agroecosystem) using commercially available software. The land area of the agricultural land uses was overestimated by 6.5% in one region (Lubbock County, TX, USA) and underestimated by about 21% in an adjacent region (Terry County, TX, USA). The total estimated wind erosion potential for Terry County was about four times that estimated for adjacent Lubbock County. The difference in potential erosion among the counties was attributed to regional differences in surface soil texture. In a comparison of different soil map scales in Terry County, the generalised soil map had over 20% more of the land area and over 15% greater erosion potential in loamy sand soils than did the detailed soil map. As a result, the wind erosion potential determined using the generalised soil map was about 26% greater than the erosion potential estimated by using the detailed soil map in Terry County. This study demonstrates the feasibility of scaling up from fields to regions to estimate wind erosion potential by coupling a field-scale wind erosion model with GIS and identifies possible sources of error with this approach. Published by Elsevier Science B.V.

Keywords: Wind erosion; Soil texture; Land use classification; Erosion models

1. Introduction

Wind-induced soil erosion (wind erosion) can have a significant impact on agricultural land uses (agroecosystems) that are essential to human well-being. Factors that affect wind erosion such as surface vegetative and other cover, soil properties, and

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0167-8809/00/$ – see front matter Published by Elsevier Science B.V.
PII: S0167-8809(00)00229-2

land use usually change spatially and temporally at the field-scale to produce important field-scale variations in wind erosion. Accurate estimation of wind erosion when scaling up from fields to regions, while maintaining meaningful field-scale process details, remains a challenge.

Recent work by Kirkby and others (Kirkby, 1998; Kirkby et al., 1996) suggests factors critical to the erosion process may vary depending upon spatial scale, with different processes dominant at each hierarchal spatial level. For example, at the scale of the single erosion plot, the timing and volume of overland flow is critical. At coarser scales, topography, soil vegetative patterns and other factors become more important. In this approach, different models are required at varying scales to accommodate the particular processes dominating at the level simulated. Models at coarser scales may simplify or integrate over processes dominant at finer scales or new models may be needed for processes unique to the coarser scale. In this way, modelling at coarser scales compromises between detailed process modelling with demanding data and computational requirements and reasonable model simulation times.

Another approach that has been used in erosion prediction to scale up from the field level to the region or watershed level is to couple erosion models with geographic information systems (GIS). Geographic information systems are specialised computer software used to display and analyse spatial data, and are being increasingly used in soil erosion research (McDonnell, 1998). The general approach for using GIS is to display factors important in an analysis as separate layers or maps in the GIS. The various layers are overlaid to determine the combination of factors to be used in the model. A thorough presentation of the application of GIS in water resource management and hydrology is provided by Kovar and Nachtnebel (1993). Application of an erosion model to a GIS may be loosely or tightly coupled or linked (Poiani and Bedford, 1995; McDonnell, 1998). In the loosely linked approach, relevant information is passed back and forth between the GIS and the model. Tightly linked models operate within the GIS and range in complexity from simple book-keeping and classification to detailed modelling. A detailed review and examples of the different GIS-modelling approaches is provided by Poiani and Bedford (1995).

Most of the GIS applications to erosion models to date have focused on water erosion projects. The universal soil loss equation (USLE), a field-scale water erosion model (Wischmeier and Smith, 1978) that may be loosely or tightly linked to GIS, has been used with GIS to estimate water erosion for a 600,000 ha region in Ontario (Snell, 1985), a 61,000 ha watershed in Idaho (Prato et al., 1989), and a 1400 ha watershed in New Brunswick, Canada (Mellerowicz et al., 1994). A modified version of the USLE was used to estimate erosion in a 8.6 million hectare region in northern Thailand (Liengsakul et al., 1993).

Several models such as ANSWERS (Beasley and Huggins, 1982) and TOPMODEL (Beven and Kirkby, 1979; Beven et al., 1984) predict erosion and runoff using spatially distributed inputs that are very well suited for the tightly linked approach with GIS (Brown et al., 1993). Such models may have distinct advantages over older models such as USLE, depending on the use of the output. For example, new relationships can be easily incorporated and they may be more easily validated because they may deal with individual erosion events (De Roo et al., 1989). ANSWERS was successfully applied to a watershed in The Netherlands (De Roo et al., 1989) and a typical piedmont watershed in north Carolina (Brown et al., 1993).

The application of GIS to wind erosion prediction has not been widely tested. A wind erosion potential map was created for a 1500 km^2 region of Kenya using a model based on herbaceous and coarse fragments ground cover applied to a GIS database (Grunblatt et al., 1992). Wu et al. (1997) determined the wind erodibility of Finney County, Kansas using GIS coupled with the climatic and soil erodibility indexes of the wind erosion equation (Woodruff and Siddoway, 1965).

Problems may develop when scaling up estimates of erosion prediction to regional or watershed scale using field-scale models with GIS. Four major scale-related issues have been identified (Moore et al., 1993): (i) element size in which homogeneity is assumed; (ii) the method of analysis used to derive the attribute values; (iii) merging data with different resolutions, accuracies and structures and (iv) scale differences between model process representation and data available for model parameterization. The precise effect of changing scales depends on factors such as differences in climate, topography, soil, and

geology that govern processes and discontinuities or boundaries separating soil types, geologic formations or land covers (Arnold et al., 1998). Some parameters that are important in a model or process may experience wide variability even within a single map unit. For example, in a study of two small adjacent watersheds mapped as the same soil near Coshocton, Ohio, the amount of measured runoff between the two watersheds varied by a factor of 2.5 (Bonta, 1998). Scaling up will necessitate including and combining soils with even more widely different properties.

This was demonstrated in a study of chemical movement that tested two scales of soil mapping provided by the United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS) (Wilson et al., 1996). In this study, model outputs generated using generalised soil data provided by the NRCS State Soil Geographic Database (STATSGO) were different at the 0.01 significance level to that provided by the more detailed Soil Survey Geographic Database (SSURGO). The authors' concluded that model predictions varied with the choice of climate and soil inputs.

The main objectives of our study were: (1) to evaluate the feasibility of using a field-scale wind erosion model such as the revised wind erosion equation (RWEQ) with GIS to scale up to regional levels and (2) to quantify the differences in wind erosion estimates produced by different scales of soil mapping used as data layers in the model.

2. Methods

The study area included Terry and Lubbock Counties, located in the southern high plains of west Texas, USA (Fig. 1). The region has a continental semiarid climate with a mean annual precipitation of 475 mm, maximum temperature of 43°C and minimum temperature of −27°C. The region experiences significant

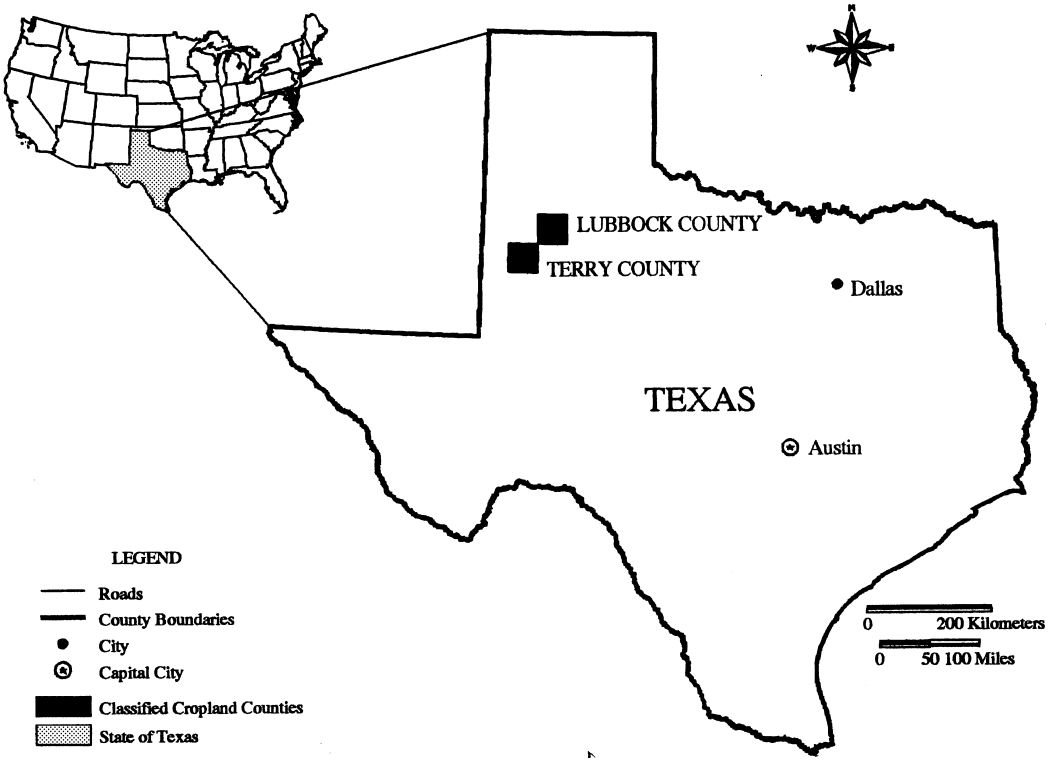

Fig. 1. Location of Lubbock and Terry Counties in Texas, USA.

winds that often produce blowing dust. The average wind speeds range from 16 to 24 km h^{-1} and speeds more than 80 km h^{-1} are common (NOAA, 1982; Holliday, 1995). The surficial soils of the region consist primarily of Holocene aeolian material, silt and sand of the Quaternary Blackwater Draw Formation, and Quaternary and Pliocene lake deposits that crop out locally (Collins, 1990). The dominant soils are classified as Aridic Paleustalfs, Paleustolls, and Calciustepts in the US soil classification system (Soil Survey Staff, 1998) and Eutric Planosols, Luvic Kastanozems, and Calcic Cambisols, respectively, in the FAO system (FAO-UNESCO, 1974). Although the primary crops grown in the region are cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.), and sorghum (*Sorghum bicolor* (L.) Moench), this study also includes data for sunflowers (*Helianthus annuus* L.), corn (*Zea mays* L.), soybeans (*Glycine max* L.), onions (*Allium* spp.) and watermelons (*Citrullus lanatus* (Thunb.) Matsumura & Nakai).

Development of the GIS required acquisition and processing of several spatial data sets used in combination with a wind erosion prediction model to estimate wind erosion potential for each county by surface soil and agricultural land use. We used Landsat V Thematic Mapper (TM) scene 3037 from 13 August 1993 as our GIS base map. The scene was processed by the United States geological survey (USGS) Earth Resources Observation Systems Data Center (Sioux Falls, South Dakota, USA) to provide a georeferenced, destripped, and hyperclustered unsupervised image with 241 classes of landcover and a pixel resolution of 30 m. County boundaries and roads also were provided by the USGS.

The scene was initially classified into terrestrial land use cover classes following the procedures of Jennings (1993). In this procedure, vegetation is classified into a hierarchal system based on the scheme of The Nature Conservancy (TNC). In this scheme, croplands are identified only to the land use and not to the type of crops present. The classification scheme of TNC includes sections for the classification of cultivated crops, but these sections have yet to be developed. In this project, the TNC classification in Texas was extended to include irrigated and non-irrigated crop types in the study counties.

Since estimates of erosion by agricultural land use were needed for this simulation, it was necessary to identify the agricultural land uses on our base map. Field offices of the USDA, Farm Service Agency, in each county were visited to obtain farm plat data on the type and amount of land area of each crop in 1993. This information is provided in annual reports. Representative fields of the major crops in Lubbock County were selected to use as 'training sites'. A total of 18 farm plats representing the major combinations of crops and irrigation management systems were identified. The farm plat data were digitised in ARC/INFO (Environmental Systems Research Institute, Inc. Version 7.2.1, Redlands, CA, USA) to define the plat area and location. Through a projection transfer, the digitised coordinate data from the farm plats were converted to correspond to the Landsat TM scene. These training sites were then used to develop maps of agricultural land uses using the commercial software program Spectrum (Khoral Research, Inc., Albuquerque, NM). Spectrum software was used to provide an unsupervised classification of the scene by extension from the training points (Gonzalez-Rebeles et al., 1997). This initial classification had errors due to improper classification of pixels.

The classification by agricultural land use was improved by two methods. First, an automated computer algorithm was employed that corrected for misclassification of single pixels. This procedure was used on a pixel when all of its nearest neighbours were in a different class than the class of the test pixel. Visual inspection also was used to manually convert single farm fields to homogeneous units in regions where significant misclassification was visually apparent.

Since surface soil texture data were needed to employ the wind erosion model, a soil texture GIS layer was acquired. Two scales of soils data provided by the USDA, NRCS were used in this study. A detailed soil map was used in Lubbock County and detailed and generalised soil maps were tested in Terry County. The generalised soil map is part of the STATSGO database (http://www.ftw.nrcs.usda.gov/statsgo.html) and has a map scale of 1:250,000. The minimum area represented on the generalised soil map is ~625 ha (1544 ac). The detailed soil maps are part of the SSURGO database (http://www.ftw.nrcs.usda.gov/ssurgo.html). The SSURGO Terry County soil map scale is 1:24,000 and the SSURGO Lubbock County soil map scale is 1:20,000. The minimum area represented on the SSURGO maps is about 2 ha (5 ac).

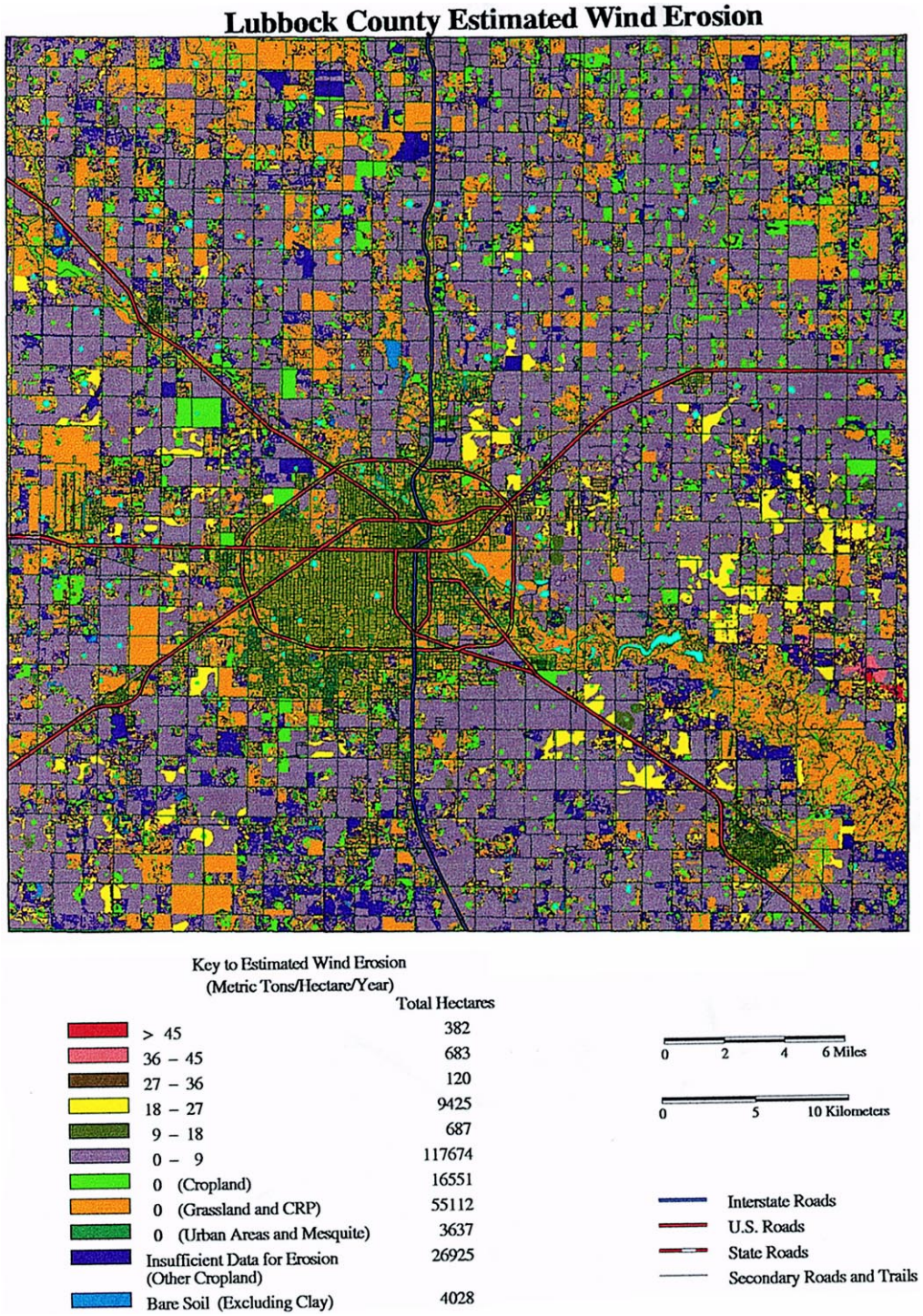

Fig. 2. Estimated wind erosion for Lubbock County, TX, using the RWEQ and assuming 6 ha (10 ac) fields for each combination of land use and soil. The SSURGO was used for the soil map layer.

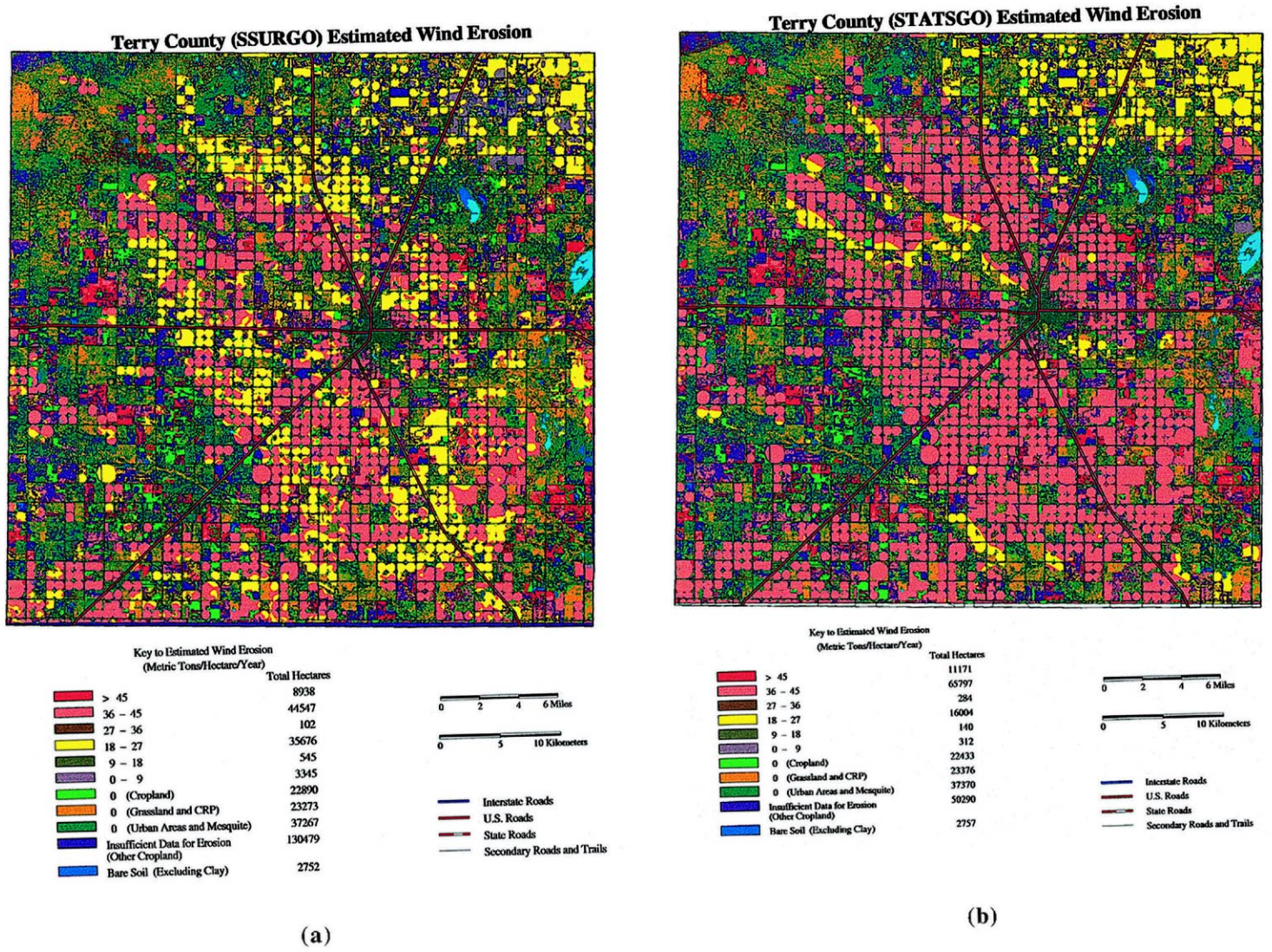

Fig. 3. Estimated wind erosion for Terry County, TX, using the RWEQ with the SSURGO detailed soil map layer (a) and the STATSGO generalised soil map layer (b) and also assuming 6 ha (10 ac) fields for each combination of agricultural land use and soil.

The RWEQ (Fryrear, 1998; Fryrear et al., 1998), was used to estimate the wind erosion potential for each agricultural land use and surface soil texture combination identified in this study. The RWEQ is a process-based, empirical model requiring simple input data for soils, tillage, and crops. The soils data needed includes specification of soil texture (or amount of sand, silt, and clay), and amounts of coarse fragments, calcium carbonate, and organic matter. The tillage/crop information needed is date of planting and/or tillage, crop type, type of tillage tool, and amount and date of irrigation. The weather data is simulated based on historic weather records for the region. The size and shape of the field must also be specified. The erosion data used in this study are described as a potential because we were unable to use the actual shape and size of each field in the study area as needed for quantitative estimates of erosion in RWEQ. Since RWEQ requires that field size and shape be identified, we estimated erosion for a round 6 ha (10 ac) field for each major land use. The management inputs used in this study included only conventional practices used in the region. The soil texture and land use maps were over-laid to determine all combinations of land use by soil texture. Irrigation amounts were determined by using average values supplied by the High Plains Underground Water Conservation District No. 1 along with farmer interviews. The RWEQ weather file from Lubbock, TX, was used to represent the weather for both counties. The estimated erosion by land use was assigned to map areas by texture to develop the final wind erosion maps for Lubbock (Fig. 2) and Terry Counties (Fig. 3).

3. Results

3.1. Land use classification

The initial classification of land uses included areas that had obvious inclusions of contrasting pixels. After automated and manual supervision (correction), the GIS estimates were slightly greater than the USDA-reported land area estimates in Lubbock County and somewhat greater than the USDA-reported land area in Terry County. For purposes of this study, the percent deviation of the estimated land area from that reported by the USDA-Farm Service Agency is defined as an error in classification (Eq. (1)).

$$\text{Percent error} = \left[\frac{(\text{estimated area} - \text{USDA-reported area})}{\text{USDA-reported area}}\right] \times 100 \quad (1)$$

The final total error was only 6.5% for Lubbock County and −20.9% for Terry County (Table 1). The total areas listed in Table 1 represent only the totals of the land areas compared in the table and not the total area in the county. Cotton was grown in about 68% of the area tested in Lubbock County and had an error of 15% overall. Cotton was grown in about 57% of the area tested in Terry County and had an error of −25% overall. Non-irrigated wheat had a significant error in both counties but this error was not important in this study, because no wind erosion occurred in the wheat land. Other land use with significant errors represented very little land area in the study area or were not erodible land uses (e.g. Conservation Reserve Program (CRP) grassland and permanent grass).

3.2. Wind erosion estimates

The pattern and geographic distribution of estimated wind erosion using the detailed SSURGO soil maps (and assuming 6 ha fields) for Lubbock County (Fig. 2) and Terry County (Fig. 3) are markedly different. Lubbock County is dominated by areas estimated to produce 0–9 mt ha^{-1} per year. Terry County is dominated by large non-erodible areas of mesquite, a low shrub in this area, and large areas with 18–27 and 36–45 mt ha^{-1} per year estimated wind erosion (Fig. 3(a)).

Erosion rates (t ha^{-1} per year) were very sensitive to the type of land use present (Table 2). Wheat, CRP and grass covered the soil surface during the erosive time of year, the RWEQ estimated no erosion for these land uses. Onions resulted in the most erodible soil surface. The soil is very intensively tilled for onions and little residue is present to protect the soil surface from the force of the wind. Watermelons were the next most erosive crop.

The amount of wind erosion in metric tons per hectare per year for each crop also is presented by surface soil texture in Table 2. Wind erosion tended to decrease as the amount of clay in the surface soil

Table 1
Comparison of reported and estimated areas for selected agricultural land uses in Lubbock and Terry Counties, USA

Agricultural land use	Lubbock County			Terry County		
	USDA-reported area (ha)	Estimated area (ha)	Error (%)[a]	USDA-reported area (ha)	Estimated area (ha)	Error (%)[a]
Irrigated cotton	80227.3	91142.9	13.6	49320.7	60878.4	23.4
Non-irrigated cotton	26400.0	30571.0	15.8	50769.9	13955.0	−72.5
Irrigated wheat	419.1	432.7	3.2	1868.7	5885.3	214.9
Non-irrigated wheat	15640.6	11942.2	−23.6	9269.8	16420.4	77.1
Irrigated sunflower	553.3	364.4	−34.1	8.9	3368.6	37734.5
Non-irrigated sunflower	303.9	642.7	111.5	0.0	8219.0	–
Irrigated corn	641.0	1615.7	152.1	218.3	294.1	34.7
Irrigated onion	183.0	601.3	228.5	20.9	520.5	2392.6
Irrigated soybean	394.4	1176.0	198.2	0.0	280.5	–
Irrigated watermelon	115.0	708.1	515.8	245.7	115.7	−52.9
Sorghum	5380.3	6199.5	15.2	13000.5	5649.7	−56.5
CRP/grass[b]	26352.0	21395.4	−18.8	49408.0	22082.7	−55.3
Total	156609.9	166791.9	6.5	174131.3	137670.0	−20.9

[a] Error: ((estimated area − USDA-reported area)/USDA reported area) × 100.
[b] CRP: conservation reserve program.

increased. RWEQ estimated no erosion on clay surface soils and the highest erosion rates for the fine sand soils. We used fine sandy loam when estimating erosion for areas designated as ‘variable soils’ in the USDA maps. Irrigation tended to reduce the predicted erosion rates for a given land use and soil texture. According to the model, non-irrigated soils were up to seven times more erodible than irrigated soils (Table 2).

The amount of land area and the estimated erosion potential for each agricultural land use are listed by county in Table 3. Cotton was the dominant crop in both counties. Over one-fourth of the land area in Terry County could not be classified into a particular land use but was identified as cropland and assigned to the category ‘other cropland’. For purposes of calculating erosion potential, these areas had the same management input as cotton land in RWEQ.

Lubbock County was dominated by clay loam and loam soils and Terry County had mainly loamy fine sand and fine sandy loam soils (Table 4). The erosion potential was greatest for the fine sandy loam in Lubbock County and the loamy fine sand in Terry County. The detailed soil maps of Terry County also included

Table 2
Estimated wind erosion per hectare per year as predicted by the RWEQ for 6 ha fields by surface soil texture and major agricultural land uses with irrigation (Irrig.) and without irrigation (Non-Irrg.)

Agricultural land use	Clay loam		Sandy clay loam		Loam		Fine sandy loam		Loamy fine sand		Fine sand		Variable	
	Irrg.	Non-Irrg.	Irrg.	Non-Irrg.	Irrg.	Non-Irrg.	Irrg.	Non-Irrg.	Irrg.	Non-Irrg.	Irrg.	Non-Irrg.	Irrg.	Non-Irrg.
Cotton	0.7	0.7	1.6	1.6	6.9	6.9	21.8	21.8	42.0	43.1	68.0	70.5	21.8	21.8
Sunflowers					1.6	13.1	13.1	43.3	37.3	82.9	79.1	135.6		43.3
Corn			1.1		3.1		10.9		22.7		37.8		10.9	
Soybeans			1.3		4.0		13.8		26.7		50.2		13.8	
Onions	5.8		16.0		56.9		197.6		370.6		567.5		197.6	
Watermelons			0.9		7.3		34.2		71.8		120.9		34.2	
Sorghum	0.7		1.6		5.8		19.3		38.2		62.2		19.3	
Other Cropland	0.7		1.6		6.9		21.8		42.0		68.0		21.8	
Bare Soil		0.7		1.6		6.9		21.8		43.1		70.5		21.8

Table 3
The percent of land area and the estimated erosion potential for each agricultural land use by county

Agricultural land use	Lubbock County		Terry County	
	Estimated erosion	Area potential	Estimated erosion	Area potential
Cotton	61.5	67.9	39.5	48.0
Wheat	6.3	0.0	11.8	0.0
Sorghum	3.1	3.8	3.0	3.1
Corn	0.8	0.4	0.2	0.1
Onion	0.3	3.2	0.3	2.2
Soybeans	0.6	0.2	0.2	0.1
Sunflower	0.5	1.4	6.1	14.1
Watermelons	0.4	0.5	0.1	0.1
Other Cropland	13.6	19.4	26.3	31.1
CRP/Grass[a]	10.8	0.0	11.6	0.0
Bare Soil	2.1	3.3	1.2	1.2
Total hectrares	197890		189706	

[a] CRP: conservation reserve program.

about 0.3% of the land area in sandy clay loam, fine sandy clay loam, and gravely loam but these lands were in land uses that produced no estimated erosion and so were not shown in Table 4. The total erosion potential for Terry County (detailed scale) was about four times that estimated for Lubbock County. The generalised STATSGO soil map estimated a greater amount of sandy soils than the detailed SSURGO map in Terry County (Fig. 4). The generalised soil map had over 20% more of the land area, and over 15% greater erosion potential, in loamy sand soils than the detailed soil map. As a result, the wind erosion potential determined using the generalised soil map was about 26% greater than the erosion potential estimated using the detailed soil map in Terry County.

4. Discussion

4.1. Land use and soils

To evaluate how well we classified the land use, estimates based on analysis of the Landsat images were compared to estimates made by the USDA (Table 1). The errors in the classification of the land use varied by county. This result may, in part, be due to the location of the training sites. All training sites were located in Lubbock County, which had the least error in land use classification. Time and funding constraints did not allow us to identify training sites in both counties. The largest errors in Terry County were for areas incorrectly identified as sunflowers or onions (Table 1). Sunflowers were estimated to have been grown on over 6% of the cropland in Terry County (Table 4) whereas USDA estimated the true land area in sunflowers to be $<1\%$. The estimated land in sunflowers contributed over 14% of the potential erosion in Terry County.

The difference in land use classification errors between Lubbock and Terry Counties was surprising because the counties are adjacent and are shown on the same Landsat scene. It may be possible that some of the differences in land use classifications were caused by differences among the counties in surface soil textures associated with the same crop. The counties had

Table 4
The percent of land area and estimated erosion potential for each surface soil texture, by county and map scale

Surface soil texture	Soil map scale					
	Detailed				Generalised	
	Lubbock County		Terry County			
	Estimated area (%)	Estimated potential (%)	Estimated area (%)	Estimated potential (%)	Estimated potential (%)	Estimated area (%)
Clay	1.9	0.0	0.2	0.0	0.0	0.0
Clay loam	46.6	4.3	0.2	0.0	0.0	0.0
Loam	28.5	26.4	4.1	1.0	1.2	0.2
Fine sandy loam	22.5	67.1	43.5	28.2	24.5	14.5
Loamy fine sand	0.1	1.1	50.4	68.8	72.7	83.8
Fine sand	0.0	0.0	1.3	2.0	1.6	1.5
Variable	0.3	1.2	0.1	0.1	0.0	0.0

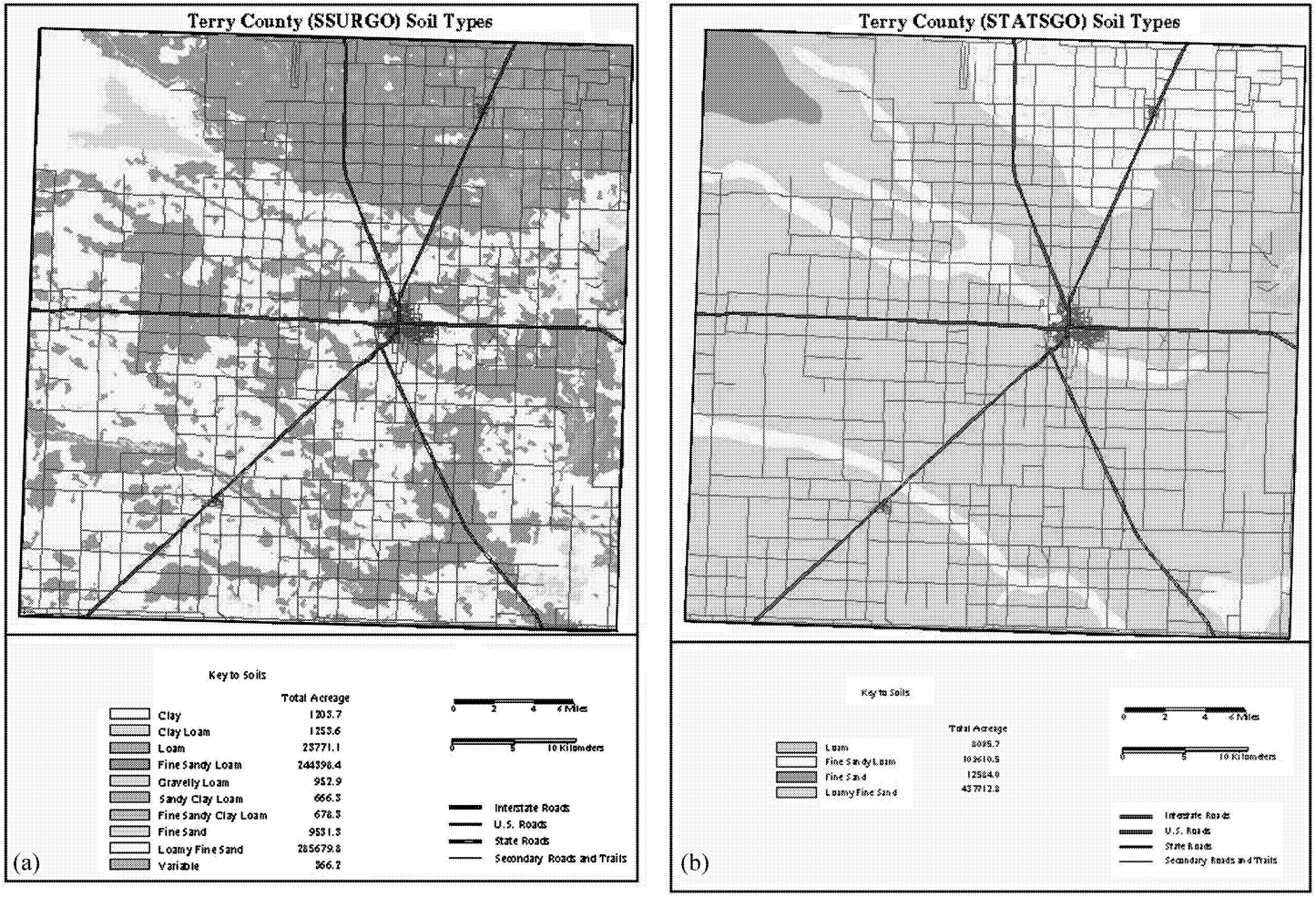

Fig. 4. The SSURGO detailed soil map layer (a) and STATSGO generalised soil map layer (b) for Terry County, TX.

wide differences in surface soil textures as indicated in Table 4. Lubbock County had more clay loam soil and far less loamy fine sand soil than Terry County. We suspect that differences in surface soil texture may have contributed to differences in classification of the same crop in each county due to difference in radiance produced by different soil textures. For example, it may be that some loamy fine sand soils producing dryland cotton, dominant in Terry County, had a slightly different radiance than the same crop grown on clay loam soils in Lubbock County. The difference in radiance may have caused the dryland cotton system to be misclassified in Terry County. It is well known that soil spectral contributions toward canopy radiance play a significant role in the total path radiance. Many specialised spectral indices have been developed to characterise vegetation canopies (Asrar, 1989). Most try to enhance the effect of vegetation while removing the effect of soils. The effect of soil is particularly important in partial canopies (similar to those of this region) because soil background conditions exert considerable influence (Huete, 1988). We did not attempt any special soil reflectance filtering in this study. The differences in surface soil texture between the counties had a profound effect on the estimated wind erosion potential. Loamy fine sand soils accounted for about 50% of the soils in Terry County and two-thirds of the potential wind erosion (Table 4). Lubbock County abuts the northeast corner of Terry County (Fig. 1) yet has less than 1% of the soils identified as loamy fine sand, accounting for about 1% of the total wind erosion potential. Most of the wind erosion potential of Lubbock County occurred on the fine sandy loam soils. The total estimated wind erosion potential of Terry County was about four times that estimated for Lubbock County.

The difference in surface texture among the counties has been attributed to differences in deposition of aeolian sediments with increasing distance from a sediment source. Studies by Seitlheko (1975) have demonstrated a decreasing mean sand particle size with distance from the Pecos River, located southwest of Terry and Lubbock Counties.

4.2. Map scale differences

Soil maps at detailed (Fig. 4(a)) and generalised (Fig. 4(b)) scales were tested in Terry County to investigate the effect of map scale on wind erosion prediction. The detailed SSURGO soil map contained much smaller homogeneous map units (about 2 ha) than the generalised STATSGO soil map (about 625 ha). The smaller soil map units identified in the SSURGO map allowed for more detailed separation of the soils into more classes. Only four surface soil textures were identified on the STATSGO map: loam, fine sandy loam, loamy fine sand, and fine sand. In contrast, 10 different textural classes were identified on the detailed SSURGO soil map: clay, clay loam, sandy clay loam, fine sandy clay loam, loam, gravely loam, fine sandy loam, loamy fine sand, fine sand and variable texture. The six new classes listed in the detailed soil map (clay, clay loam, gravely loam, sandy clay loam, fine sandy clay loam and variable texture class) combined for a total of only about 0.9% of the total land area. The greatest impact was the distribution of soils in the sandy soil classes.

The generalised STATSGO map had about 73% loamy fine sand that produced about 84% of the wind erosion potential of Terry County (Table 3). About 23% of the loamy fine sand was placed in other map units and the wind erosion potential of the loamy fine sand was reduced about 15% when the detailed soil map was used. When the erosion potential of all combinations of land use and soils were summed for both soil map scales, the estimated wind erosion potential when using the generalised STATSGO soil map was 26% greater than that estimated using the detailed SSURGO map.

Most of the erodible areas identified by the generalised STATSGO soil map were estimated to produce 36 to 45 mt ha^{-1} per year soil loss (Fig. 3(b)). These areas can be seen to be mapped as loamy fine sand soils in Fig. 4(b). In contrast, the wind erosion map produced when using the detailed SSURGO soil map layer had many more areas with an estimated 18–27 t ha^{-1} per year soil loss (Fig. 3(a)). The areas with 18–27 t ha^{-1} per year soil loss were generally identified as fine sandy loam in Fig. 4(a).

5. Conclusion

Accurate estimation of the land use by agroecosystem is important when applying erosion models such as RWEQ. In this study, we had less error in land

use classification in Lubbock County (6.5%), where the training sites were established. Terry County had about three times the total error in land use classification (−21%). The Landsat scene used in this study covered a large region and included land uses that were found on a wide range of soils. We believe the error was caused by differences in surface soil associated with the land uses used as training sites because we did not allow for differences in soils when classifying the scene by agricultural land use. The misclassification by land use may be improved by applying more training sites that represent the full range of soils utilised by each land use or by using much more sophisticated algorithms that remove the effect of soils from the spectral signature before applying the training program. Such analyses were beyond the scope of this study.

The map scale used in estimating erosion may have a profound impact upon the final erosion estimate. We compared the erosion estimates using a generalised STATSGO soil map with a more detailed SSURGO soil map. Soil map units naturally have inclusions of other soils (not the same as identified in the map unit name) that may not be observed at some scales of mapping but are readily observed at more detailed scales. Much smaller soil units were mapped in Terry County on the SSURGO soil map and over twice the number of surface soil textures were identified. As a result, there was about 26% greater wind erosion potential when the general soil map was used for the soil layer than when we used the detailed soil map layer.

Natural spatial variation of soils across a region also may produce variations in erosion estimates. In the study area, aeolian processes have produced differences in surface soil textures across the region from southwest to northeast. Surface soils are much sandier in Terry County than in Lubbock County. As a result, Terry County had about 4 times greater wind erosion potential than Lubbock County. It would be interesting to test how these counties might be combined in yet a smaller scale map (more generalised). It is probable that the region would be classified as either fine sandy loam or loamy fine sand. Although the differences in these surface soil textures appear small, they can have profound impact on wind erosion estimates. In this simulation, the loamy fine sand soils were from two to three times as erosive as the fine sandy loam soils.

The natural variation in soils across a region, and within the same region but discernable at different scales of mapping, make it evident that care must be taken when combining units as we scale up from fields to regions. Although we have demonstrated differences in erosion potential caused by scale differences in estimates of surface soil textures, similar results may be produced for changes in any factors that are critical in model estimates.

6. Disclaimer

Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Government.

Acknowledgements

The Texas Cooperative Fish and Wildlife Research Unit is jointly sponsored by the Texas Parks and Wildlife Department, Texas Tech University, US Geological Survey, and the Wildlife Management Institute. This work contributes to the Global Change and Terrestrial Ecosystem (GCTE) Soil Erosion Network, which is a Core Project of the International Geosphere–Biosphere Program (IGBP). The authors are grateful to Danny Decker, Farm Service Agency CED of Terry County, Alan Mackey Farm Service Agency CED for Lubbock County; Dean Holder, USDA-ARS; and Alejandro Amante-Orozco, Texas Tech University, for assistance with data collection and compilation.

References

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment part I: model development. J. Am. Water Res. Assoc. 34, 73–89.

Asrar, G., 1989. Theory and Application of Optical Remote Sensing. Wiley, New York.

Beasley, D.B., Huggins, L.F., 1982, ANSWERS — User's Manual. Department of Agricultural Engineering, Purdue University, West Lafayette, IN.

Beven, K.J., Kirkby, M.J., 1979. A physically-based variable contributing area model of basin hydrology. Hydrol. Sci. Bull. 24, 43–69.

Beven, K.J., Kirkby, M.J., Schofield, N., Tagg, A.F., 1984. Testing a physically-based flood forecasting model (TOPMODEL) for three UK catchments. J. Hydrol. 69, 119–143.

Bonta, J.V., 1998. Spatial variability of runoff and soil properties on small watersheds in similar soil-map units. Trans. Am. Soc., Agric. Eng. 41, 575–585.

Brown, D.G., Bian, L., Walsh, S., 1993. Response of a distributed watershed erosion model to variation in input data aggregation levels. Comput. Geosci. 19, 499–509.

Collins, E.W., 1990. Geologic Significance of remotely sensed physiographic features of the Texas panhandle and adjacent regions. Geol. Circ. 90-1. Bureau of Economic Geology, Austin, TX.

De Roo, A.P.J., Hazelhoff, L., Burrough, P.A., 1989. Soil erosion modelling using 'ANSWERS' and geographical information systems. Earth Surf. Proc. Landforms. 14, 517–532.

FAO-UNESCO, 1974. Soil Map of the World, Vol. 1. Legend. UNESCO, Paris.

Fryrear, D.W., 1998. Mechanics, measurement and modeling of wind erosion. Adv. GeoEcol. 31, 291–300.

Fryrear, D.W., Saleh, Ali, Bilbro, J.D., Schomberg, H.M., Stout, J.E., Zobeck, T.M., 1998. Revised wind erosion equation (RWEQ). Wind Erosion and Water Conservation Research Unit, USDA-ARS, Southern Plains Area Cropping Systems Research Laboratory. Technical Bulletin no. 1. http://www.csrl.ars.usda.gov/wewc/rweq.htm.

Gonzalez-Rebeles, C., Parker, N.C., Sims, R.W., Lan, Y., Cano, M., 1997. Spectrum software for Texas Gap Analysis. Gap Anal. Bull. 6, 24–27.

Grunblatt, J., Ottichilo, W.K., Sinange, R.K., 1992. A GIS approach to desertification assessment and mapping. J. Arid. Environ. 23, 81–102.

Holliday, V.T., 1995. Stratigraphy and Paleoenvironments of Late Quaternary Valley Fills on the Southern High Plains. Geol. Soc. Am. Memoir 186. Boulder, CO.

Huete, A.R., 1988. A soil-adjusted vegetation index (SAVI). Remote Sens. Environ. 25, 295–309.

Jennings, M.D., 1993. National terrestrial cover classification: assumptions and definition. Gap Analysis Tech. Bull. 2, US Fish and Wildlife Service, Moscow, Idaho.

Kirkby, M., 1998. Modelling across scales: the medalus family of models. In: Boardman, J., Favis-Mortlock, D. (Eds.), Modelling Soil Erosion by Water. NATO ASI Series: Ser. I, Global Environ. Change, Vol. 55. Springer, Berlin, pp. 161–173.

Kirkby, M.J., Imeson, A.C., Bergkamp, G., Cammeraat, L.H., 1996. Scaling up processes and models from the field plot to the watershed and regional areas. J. Soil Water Conser. 51, 391–396.

Kovar, K., Nachtnebel, H.P., 1993. Application of geographic information systems in hydrology and water resources management. Int. Assoc. Hydrol. Sci. Publ. 211.

Liengsakul, M., Mekpaiboonwatana, S., Pramojanee, P., Bronsveld, K., Huizing, H., 1993. Use of GIS and remote sensing for soil mapping and for locating new sites for permanent cropland — a case study in the 'highlands' of northern Thailand. Geoderma 60, 293–307.

McDonnell, R., 1998. Applying GIS to catchment-scale soil erosion modelling. In: Boardman, J., Favis-Mortlock, D. (Eds.), Modelling Soil Erosion by Water. NATO ASI Series I, Vol. 55. Springer, Berlin.

Mellerowicz, K.T., Rees, H.W., Chow, T.L., Ghanem, I., 1994. Soil conservation planning at the watershed level using the universal soil loss equation with GIS and microcomputer technologies: a case study. J. Soil Water Conser. 49, 194–200.

Moore, I.D., Lewis, A., Gallant, J.C., 1993. Terrain attributes: estimation methods and scale effects. In: Jakeman, A.J., Beck, M.B., McAleer, M.J. (Eds.), Modelling Change Environmental Systems. Wiley, Chichester.

NOAA (National Oceanic and Atmospheric Administration), 1982. Climate of Texas. National Climatic Data Center, Climatography of the United States no. 60. Asheville, North Carolina.

Poiani, K.A., Bedford, B.L., 1995. GIS-based nonpoint source pollution modeling: consideration for wetlands. J. Soil Water Conser. 50, 613–619.

Prato, T., Shi, H., Rhew, R., Brusven, M., 1989. Soil erosion and nonpoint source pollution control in an Idaho watershed. J. Soil Water. Conser. 44, 323–328.

Seitlheko, E.M., 1975. Studies of mean particle size and mineralogy of sands along selected transects on the Llano Estacado. MS Thesis. Texas Tech University, Lubbock, TX.

Snell, E., 1985. Regional targeting of potential soil erosion and nonpoint-source sediment loading. J. Soil Water Conser. 40, 520–528.

Soil Survey Staff, 1998. Keys to Soil Taxonomy. 7th Edition. United States Department of Agriculture-Natural Resources Conservation Service. US Government Print Office, Washington, DC.

Wilson, J.P., Inskeep, W.P., Wraith, J.M., Snyder, R.D., 1996. GIS-based solute transport modeling applications: scale effects of soil and climate data input. J. Environ. Q. 25, 445–453.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses — a guide to conservation planning. Agric. Handbook 537, US Department of Agriculture, Washington, DC.

Woodruff, A., Siddoway, F.H., 1965. A wind erosion equation. Soil Sci. Soc., Am. Proc. 29, 602–608.

Wu, J., Nellis, M.D., Ransom, M.D., Price, K.P., Egbert, S.L., 1997. Evaluating soil properties of CRP land using remote sensing and GIS in Finney County, KS. J. Soil Water Conser. 52, 352–358.